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Integrated Panoramic Night Vision Goggles Fixed-Focus Eyepieces: Selecting A Diopter Setting

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ABSTRACT
Due to the design of the eyepieces of the panoramic night vision goggles (PNVG) and the newer integrated panoramic night vision goggles (IPNVG), the eyepiece will have a fixed focus. This means the eyepiece will be set to some fixed value resulting in a virtual image of the image intensifier tube at some fixed distance between infinity and the observer. This eyepiece setting is specified in terms of diopters where the diopter value is the negative of the reciprocal of the virtual image distance in meters. Cat's Eyes night vision goggles (NVGs) used by the US Navy reportedly had a fixed focus of about -1.0 diopters. This paper will discuss the theoretical basis for the diopter setting and the results of various field surveys and in-house tests to determine observers' preferences regarding eyepiece focus settings and objective measures of their resulting visual acuity.

INTRODUCTION AND BACKGROUND

The panoramic night vision goggles (PNVG) produce an intensified field of view of approximately 100 degrees horizontal by 40 degrees vertical by combining the images from a total of 4 image intensifier tube channels[1]. Both eyes see the central part of the field of view through the two inboard channels, but only the right eye sees the right outboard channel and only the left eye sees the left outboard channel. The inboard and outboard channels are combined by using two eyepieces cemented together at an angle to produce two "windows" through which the image is seen (see Figure 1). Normally, eyepiece focus is obtained by installing the eyepiece lens in a movable lens cell that can be moved closer to or further from the output of the image intensifier tube. This adjustment moves the virtual image produced by the eyepiece closer to or further from the observer. However, the PNVG eyepiece arrangement makes it almost impossible to make an eyepiece that can be moved (i.e. focused). Therefore, it is desirable to select a single, fixed focus setting for the eyepiece that would be acceptable to all potential users of the PNVGs.

There are currently a dozen PNVGs that have been fabricated under a Phase 2 Small Business Innovative Research (SBIR) program primarily funded by the US Air Force Research Laboratory Helmet Mounted Sensory Technology (HMST) program office. These PNVGs were specified to have a fixed focus eyepiece of -0.75 diopters which means the virtual image produced by the eyepieces would be located about 1.33 meters from the observer (1/0.75). Four of these PNVGs were measured using a handheld dioptometer (see Figure 2) that showed the actual settings ranged from -0.2 to -1.0 diopters[6]. These PNVGs have been flown by several aircrew members without any complaints regarding image quality and focus that could be attributed to the diopter setting indicating that a fixed diopter setting within this range should be acceptable.

The US Navy adopted the Cat's Eyes NVGs over a decade ago and only recently has converted to the newer, higher resolution AN/AVS-9 NVGs. The Cat's Eyes NVGs have a fixed-focus eyepiece, reportedly specified to be about -1.0 diopters, because of the unique "see-through" beamsplitter design. During the 10 years or so that the US Navy flew with these NVGs there was no documented indications that the pilots had any problems with the fixed focus eyepiece.

The US Air Force currently flies F4949 (AN/AVS-9) NVGs which have adjustable eyepieces with a range of about +2 to -4 diopters. These eyepieces are adjusted by the aircrew members themselves for "best focus." One approach to determining what eyepiece focus would be appropriate is to measure the settings that crewmembers are selecting for themselves currently using the adjustable eyepieces.

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All rated aircrew members must pass a flying physical before they are permitted to fly. This physical includes an eye test that measures the individual's visual acuity for both far (infinity - 0 diopters) and near (about 16 inches - about 2.5 diopters). Therefore anyone passing a flight physical should be able to focus on an image produced anywhere from 16 inches (-2.5 diopters) to infinity (0 diopters) implying that the eyepiece fixed focus lens could be set anywhere within this range (0 to -2.5 diopters). However, if the individual had to be fitted with bifocal lenses in order to see this range (near and far) this indicates the individual's accommodative range was less than 2.5 diopters. Since the upper lenses are set for the "far" vision, and this is the part of the eyeglasses the individual would be looking through to see the NVGs, it would be inadvisable to have the NVG image produced too close to the individual.

In order to obtain more information that might facilitate a selection of a fixed eyepiece focus for the new integrated panoramic night vision goggles (IPNVG), three activities were undertaken: a controlled in-house pilot study of eyepiece focus preference and repeatability, eyepiece measurement of a dozen US Navy Cat's Eyes NVGs, and measurement of USAF aircrew members' eyepiece settings using AN/AVS-9. This paper provides a summary of these efforts and the results.

Figure 1. Panoramic night vision goggles

Figure 2. Dioptometer used to measure eyepiece settings

IN-HOUSE STUDY OF EYEPIECE FOCUS SETTING

Method

A brief pilot study was conduct using AN/AVS-9 NVGs with adjustable eyepiece focus. A total of 6 observers participated. The observers ranged in age from 31 years to 47 years with a mean of 38.8 years and a standard deviation of 5.6 years (3 male, 3 female). All observers had 20/20 distance vision and wore either contacts or eyeglasses. There were two parts to this study. In the first part the NVG eyepieces were set to -0.5 diopters and -1.5 diopters and the visual acuity of the observers was measured using the "walk-back" method [2]. For the second part, observers were asked to adjust the two oculars of the NVG until they were comfortable with the result. The observer's visual acuity and eyepiece focus setting were then measured and recorded. This was done on three consecutive days for a total of three trials for each observer. All viewing was done at an "optimum" illuminance level of about 1/4 moonlight illumination.

Results

For the first part, there was no statistically significant difference in visual acuity between the two diopter eyepiece settings (-0.5 and -1.5) . The average visual acuity at -0.5 was 20/24.2 and the average for -1.5 was 20/25.0. Four of the six observers did slightly better with the -0.5 setting and two did slightly better with the -1.5 setting.

The results of the second part of the study are best represented in Figure 3. Each observer set the right and left oculars of an NVG a total of three times. The graph in Figure 3 shows the observer/ocular combination (1L through 6R) at the bottom of the chart. For each of these observer/ocular combinations, the observer set the eyepiece focus 3 times as depicted by the diamond, square, and triangle symbols shown in the legend. A line was drawn from the two extreme eyepiece settings done by each observer for each eyepiece indicating the range of settings that a particular observer set for that eyepiece. Presumably, this line is representative of the range of values for which the observer was satisfied with the setting. The horizontal line at -0.75 diopters is a potential eyepiece value to be selected for the IPNVG. Note that this -0.75 line goes through the range of 9 of the 12

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observer/eyepiece combinations. For the 3 combinations it misses (noted by a circle around the combinations - 1L, 2L, 1R), the amount it misses by is not very much. The maximum "miss" is 1L which misses by -.25 diopters. The average for the 36 readings (2 oculars, 6 observers, and 3 trials each) was -0.74 diopters; very close to the -0.75 under consideration for the IPNVG focus. The two heavy, horizontal lines show the average plus one standard deviation and the average minus one standard deviation for reference.

Figure 3. Summary of results of eyepiece focus setting. The average of all readings was -0.74 diopters.

FIELD STUDY OF EYEPIECE SETTINGS

An unpublished Air Force study conducted in the early 1990's surveyed ANVIS night vision goggle users on a number of characteristics[7]. One of the elements of the survey was for the aviators to set the eyepiece focus on the NVGs as they were trained to do. Some of the aviators had been taught to just set the eyepiece focus to zero diopters. The remaining 109 aviators adjusted the eyepiece focus for "best focus." This resulted in an average eyepiece setting of -1.1 diopters with a standard deviation of about 1.2 diopters. One problem with this survey is that the eyepiece settings were determined from the diopter scale on the NVGs. Even though the particular ANVIS night vision goggle that was used had been calibrated at the lab to insure correctness of the scale, the scale was rather course with an estimated "least count" of 1/4 diopter. To validate this data a field study was conducted at Nellis AFB, NV with experienced NVG aviators.

Method

One problem with collecting field data is the lack of control. NVG qualified pilots adjusted their NVGs as they had been trained and then were asked to let us check the eyepiece focus setting on their NVGs. Since the diopter scales on the NVGs are not always valid indicators of actual diopter setting, each ocular was measured using a dioptometer (see figure 2). Prior to measurement the dioptometer had to be adjusted for the investigator's eye by adjusting the eyepiece of the dioptometer. This was done by setting the dioptometer to zero diopters (see figure 2) and then adjusting the eyepiece for best focus while viewing a distant object (greater than 200 feet - see figure 3). Once this adjustment was done, the investigator could use the device to determine the eyepiece focus setting of the NVGs. The dioptometer was positioned at the eyepiece of the NVG (see figure 4) and then it was adjusted (using the scale portion, NOT the eyepiece adjustment) until the image in the NVG eyepiece was in good focus. Best (most repeatable) measurements were obtained by blocking light coming into the NVGs and using the scintillation pattern as a focusing target. After the dioptometer was adjusted to obtain best focus, the diopter reading was obtained directly from the scale on the dioptometer (see figure 2). The scale was marked every 0.2 diopters and could easily be interpolated to the nearest 0.05 diopters.

Data was collected from 11 aviators that flew during the data collection period. In addition, eyepiece focus settings made by 5 other aviators were also measured with 2 of the 5 participating twice to obtain an indication of repeatability.

Figure 3. Adjusting the dioptometer for investigator's eye

Figure 4. Measuring diopter setting of F4949 NVGs.

Results

The average for the 16 pilots (2 with repeated measures) for the 2 oculars (36 data points) was -0.96 diopters with a standard deviation of 0.78 diopters. This is relatively close to the -1.1 diopters obtained in the unpublished Air Force survey. The average setting for the 11 pilots that flew actual missions with the NVGs that they had adjusted during our measurement visit was -0.63 diopters with a standard deviation of 0.63.

One individual in particular had a relatively high reading of -2.5 diopters in each eye. In an effort to determine the significance of this relatively high setting, we adjusted an NVG to -0.75 diopters in each eye and asked the individual to look through the NVGs at the Hoffman 20/20 NVG tester to see if he found this setting acceptable. His response was that he could probably adapt to this setting but that when he just quickly looked into the tester (which provides a series of bar patterns of different levels of resolution), he could only see about 20/35 Snellen acuity whereas with the setting he had adjusted to (-2.5 diopters) he could readily see something better than 20/25 Snellen acuity. Whether this is a dark focus affect, an instrument myopia effect, or something else remains to be seen. However, if there are individuals within the NVG flying population that have difficulty accommodating to a fixed focus eyepiece setting of about -.75 diopters then we need to address this issue.

CAT'S EYES NVG MEASUREMENTS

Method

A total of 12 Cat's Eyes NVGs were obtained from the US Navy to measure their fixed focus eyepiece diopter setting. Since there was an indication that the Cat's Eyes might have astigmatism, a slightly different measurement strategy was used.

Figure 5. Cat's Eyes NVGs focused on distant bar target

Figure 6. Using dioptometer to measure Cat's Eyes

A grating pattern was set up at the end of a long room (150 feet away- see figure 5) and the NVG objective lens was adjusted for best focus. The dioptometer was then adjusted for the investigator's eye as before and focused to produce the best image of the vertical bars. This diopter reading was recorded and the grating was then turned 90 degrees to produce horizontal bars. Again, the dioptometer was adjusted for best focus of the horizontal bars. If astigmatism was present the horizontal and vertical bars would be in focus at different diopter settings on the dioptometer. No consistent astigmatism effect was found. A total of four observers made measurements of each of the 24 oculars.

Results

A total of 6 measurements were made for each Cat's Eye ocular: 3 measurements from one observer and 1 measurement each from 3 more observers. There was no significant difference between observer measurements. These 6 readings were averaged to obtain a single diopter value for each of the 24 oculars. The average diopter value for the 24 oculars was -0.24 diopters with a standard deviation (for the 6 readings) of 0.07 diopters. The optical power of the 24 oculars ranged from -0.07 diopters to -0.42 diopters. This is significantly different than the reported specified value of -1.0 diopters.

DISCUSSION and CONCLUSIONS

From the results of the different sections presented above, it is apparent that there is no obvious eyepiece diopter value that should be selected. The in-house study points to a -0.75 diopters as a reasonable choice, the Nellis field data suggests something between -0.6 and -1.0 diopters, and the Cat's Eyes data suggests that -0.25 was an acceptable value for Naval aviators. In addition, the unpublished Air Force survey effort noted earlier had an average eyepiece setting of -1.1 diopters with a standard deviation of about the same size[7]. The unpublished manuscript by Gleason[5] concluded with several options that all involved a fixed setting with "snap-on" auxiliary lenses. In the Gleason study, they found the best visual acuity was at -0.75 diopters, with -0.5 diopters a close second. In addition, in their "long-term" wear study they found subjects commented (unsolicited) on discomfort for the fixed -1.5 diopter setting (long-term was for a 4 hour period)[3,4]. Based on these results, it appears that a fixed focus value somewhere between -0.25 and -1.0 diopters should be reasonable. The concern with selecting too high of a minus value (e.g. -1.0) is that hyperopes (far-sighted folks) might have difficulties. On the other hand, there are some individuals that are adamant that they need a high minus value (e.g. the Nellis anecdote related previously).

Another factor that needs to be considered is the visual capability of the individual if he/she needs to remove the NVGs and just use unaided vision. If the individual is presbyopic (focus ability about gone due to age), and he/she needs glasses in order to see the NVG image set for -1.0 diopters, then that person's vision will be adversely affected if the NVGs are removed.

It is apparent that further work needs to be done in this area. However, it appears the current best solution to the fixed focus problem is probably to select either -0.5 or -0.75 diopters for a setting and provide selected "snap-on" lenses, at least for the current program of the IPNVG, to achieve other settings (to be determined). This will allow for an actual field evaluation of the IPNVG with different eyepiece focus settings and may lead to an acceptable, single value for eyepiece focus.

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BIOGRAPHY

H. Lee Task has been employed as a research scientist for the US Air Force since 1971. He has served as chief scientist for the Armstrong Aerospace Medical Research Laboratory and in March of 1997 was selected as the Senior Scientist for Human-Systems Interface of the new Air Force Research Laboratory at Wright-Patterson AFB, Ohio. He is currently involved in research and development in the areas of helmet-mounted displays, vision through night vision goggles, optical characteristics of aircraft windscreens, vision, and display systems. He has a BS Degree in Physics (Ohio University), MS degrees in Solid State Physics (Purdue, 1971), Optical Sciences (University of Arizona, 1978), and Management of Technology (MIT, 1985) and a Ph.D. in Optical Sciences from the University of Arizona Optical Sciences Center (1978). During his career he has earned 42 patents and has published more than 90 journal articles, proceedings papers, technical reports, and other technical publications.

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